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Trnka

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(54) **AUTOMATED SANDING SYSTEM**

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B25J 9/16 (2006.01)
B25J 11/00 (2006.01)
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(52) **U.S. Cl.**

CPC . **B24B 1/00** (2013.01); **B24B 19/14** (2013.01);
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(57)

ABSTRACT

A method and apparatus for sanding a number of surface features on a surface of an object. A first type of operation may be performed on the number of surface features on the surface of the object using a first end effector. Feedback laser data may be generated about the number of surface features after the first type of operation has been performed using a laser device. A second type of operation may be performed on the number of surface features using a second end effector and the feedback laser data to rework the number of surface features until the number of surface features has been reworked to within selected tolerances.

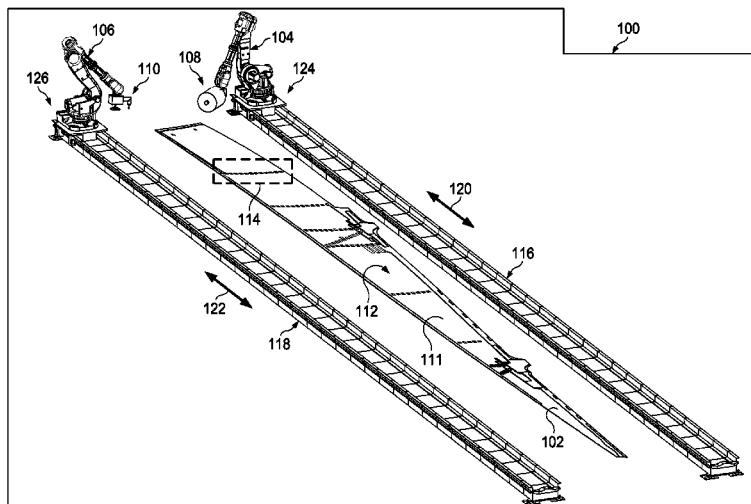
(58) **Field of Classification Search**

CPC B24B 19/14; B24B 49/12; B24B 37/013;
B24B 49/04

USPC 451/6, 5, 8, 9, 10, 57, 65, 66, 44

See application file for complete search history.

20 Claims, 13 Drawing Sheets



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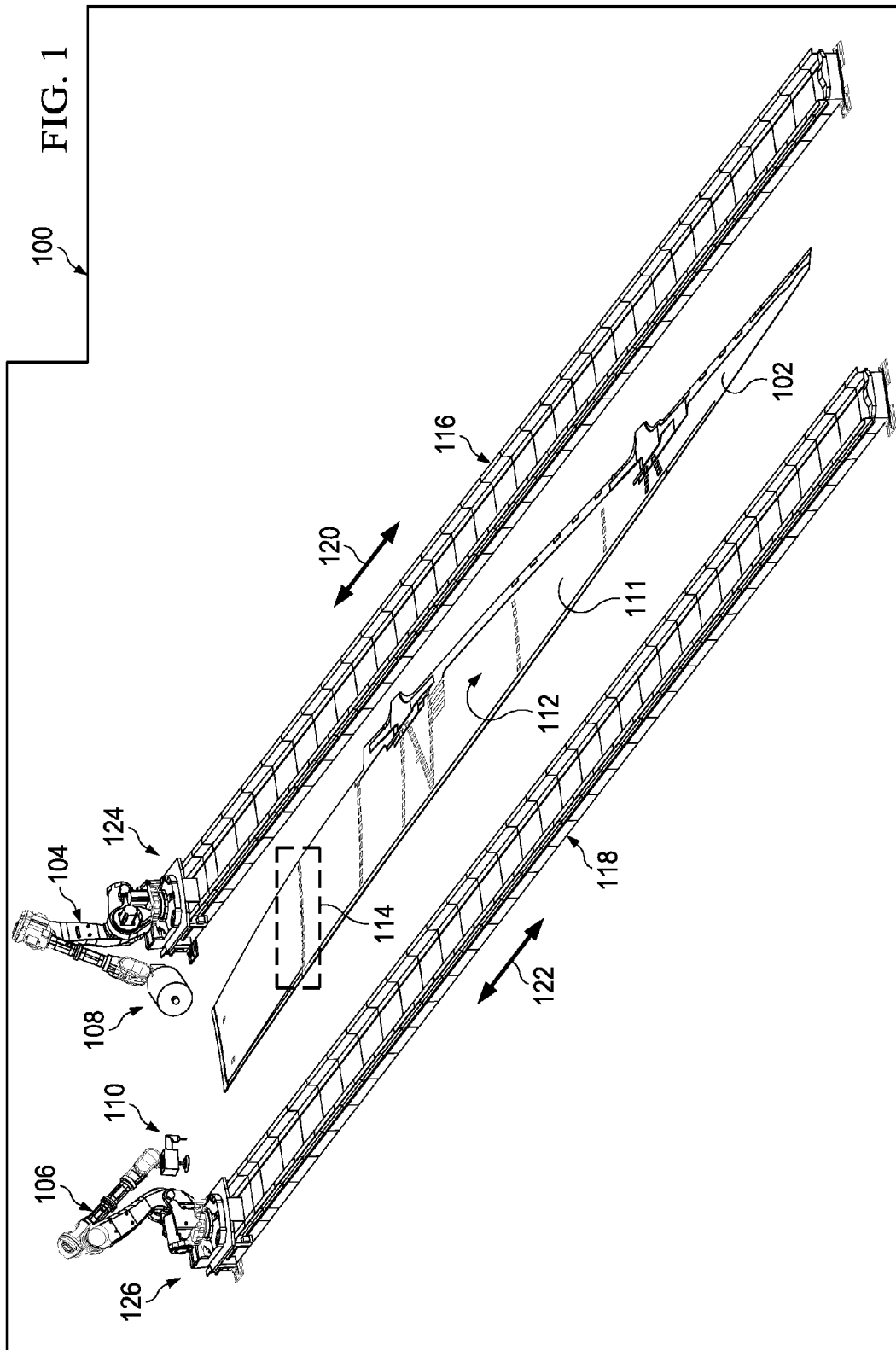
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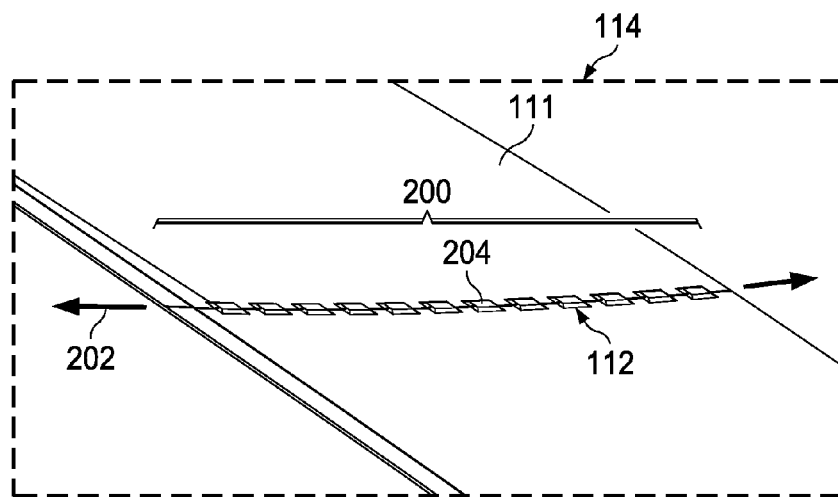


FIG. 2

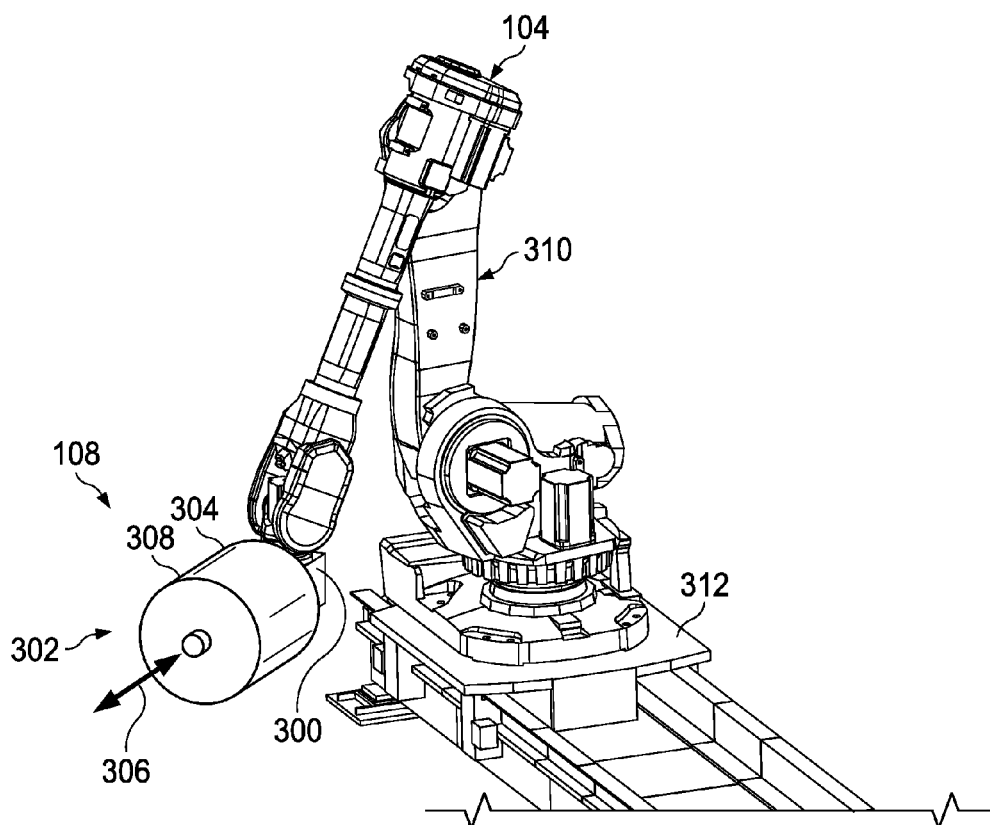


FIG. 3

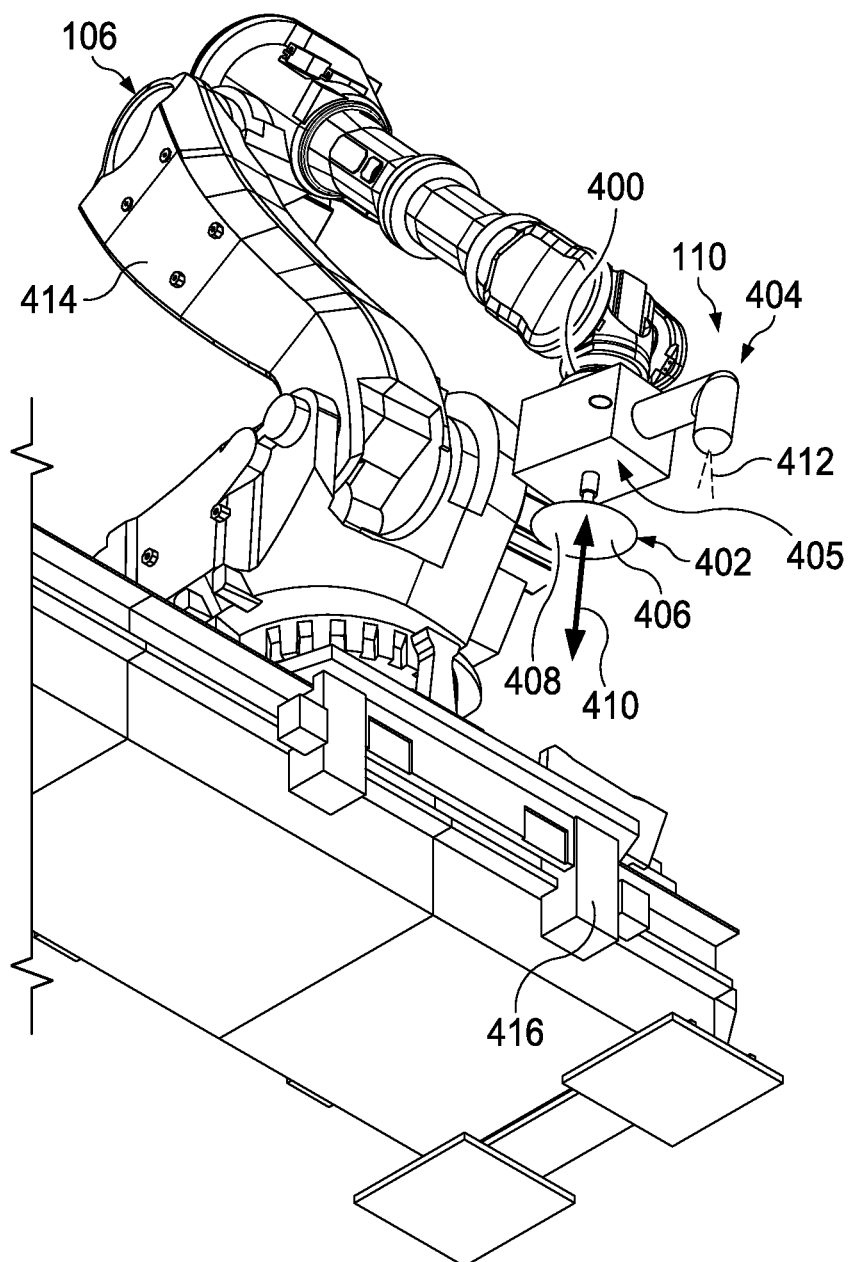
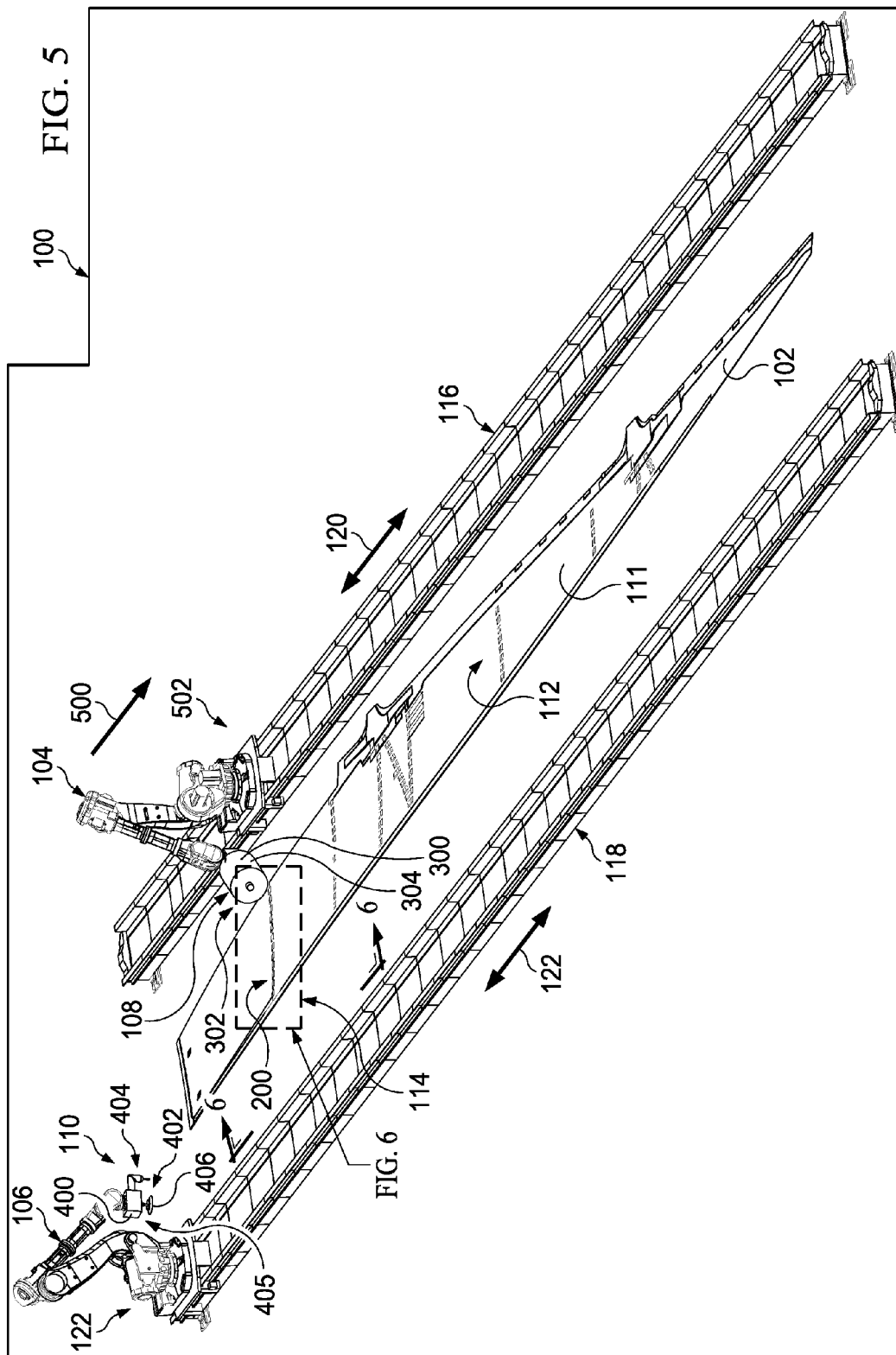


FIG. 4



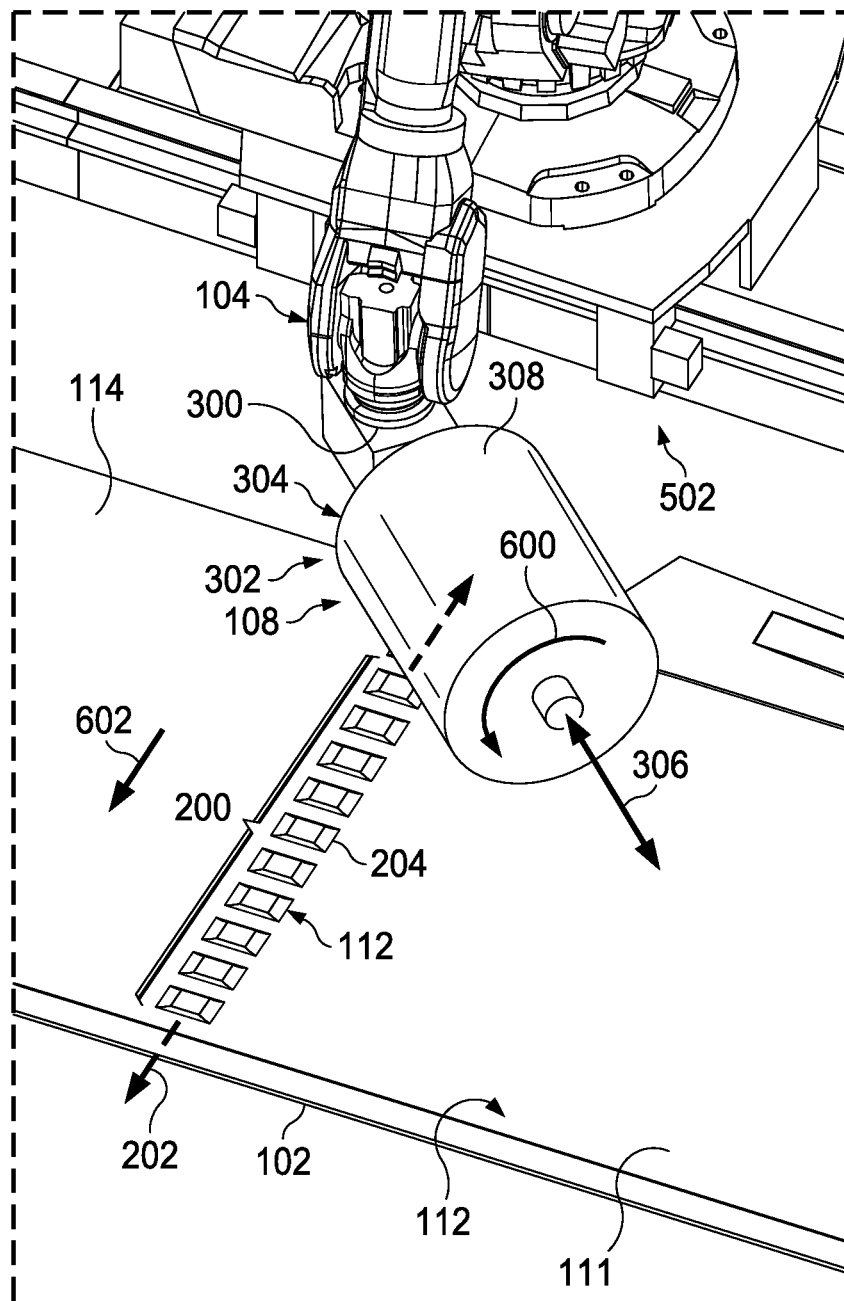
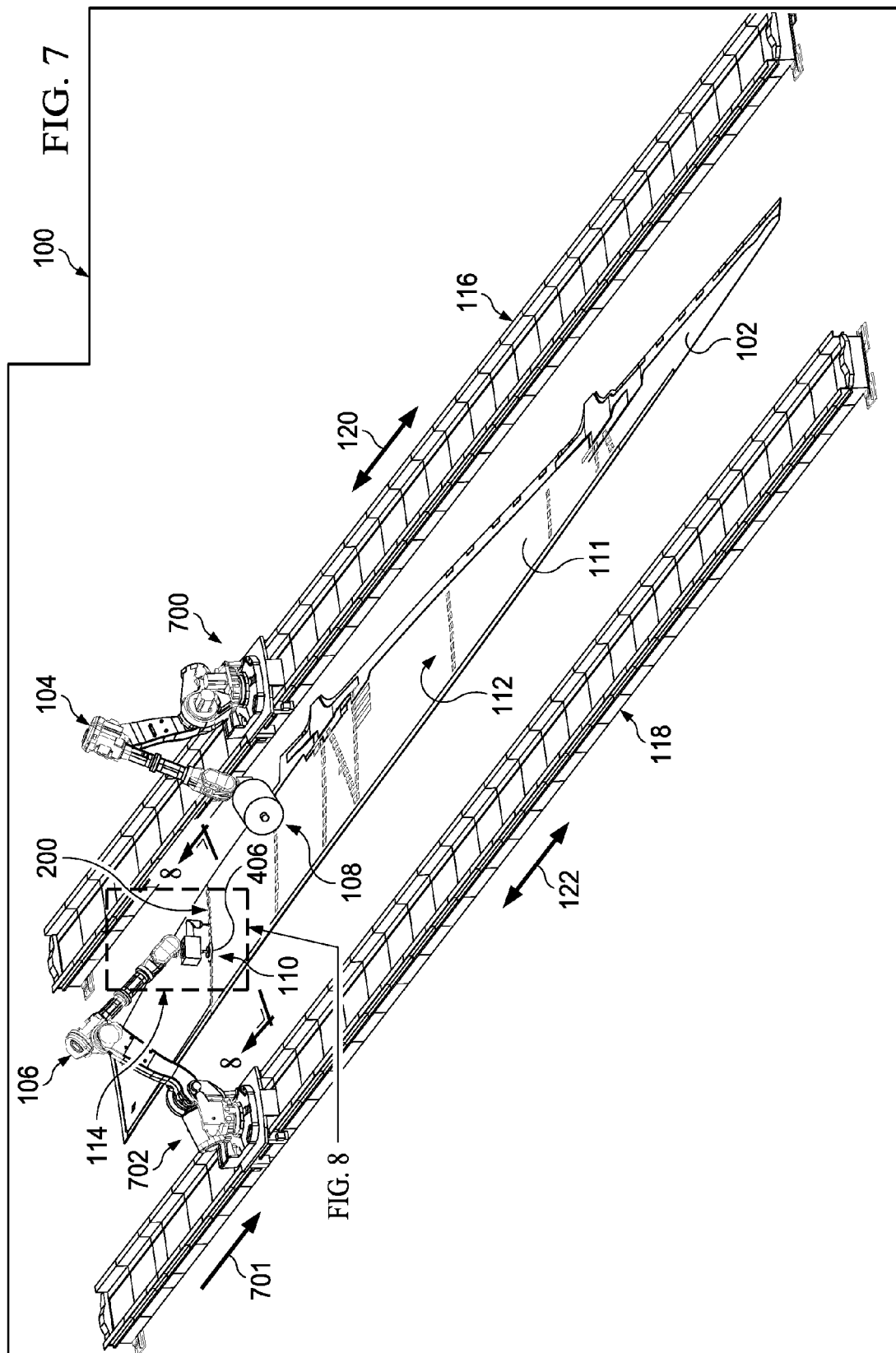


FIG. 6



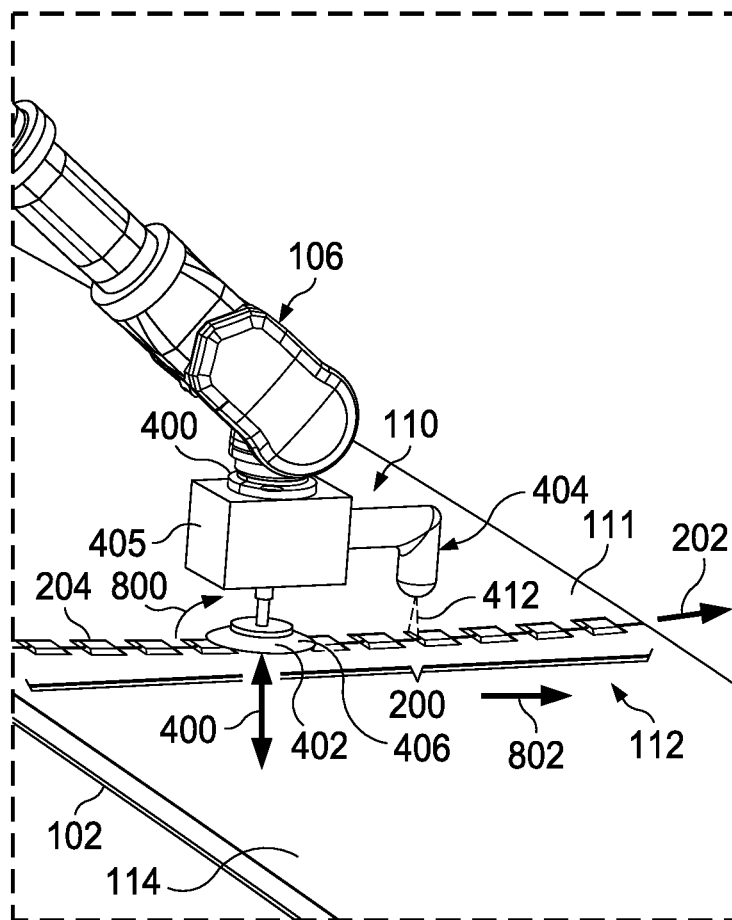


FIG. 8

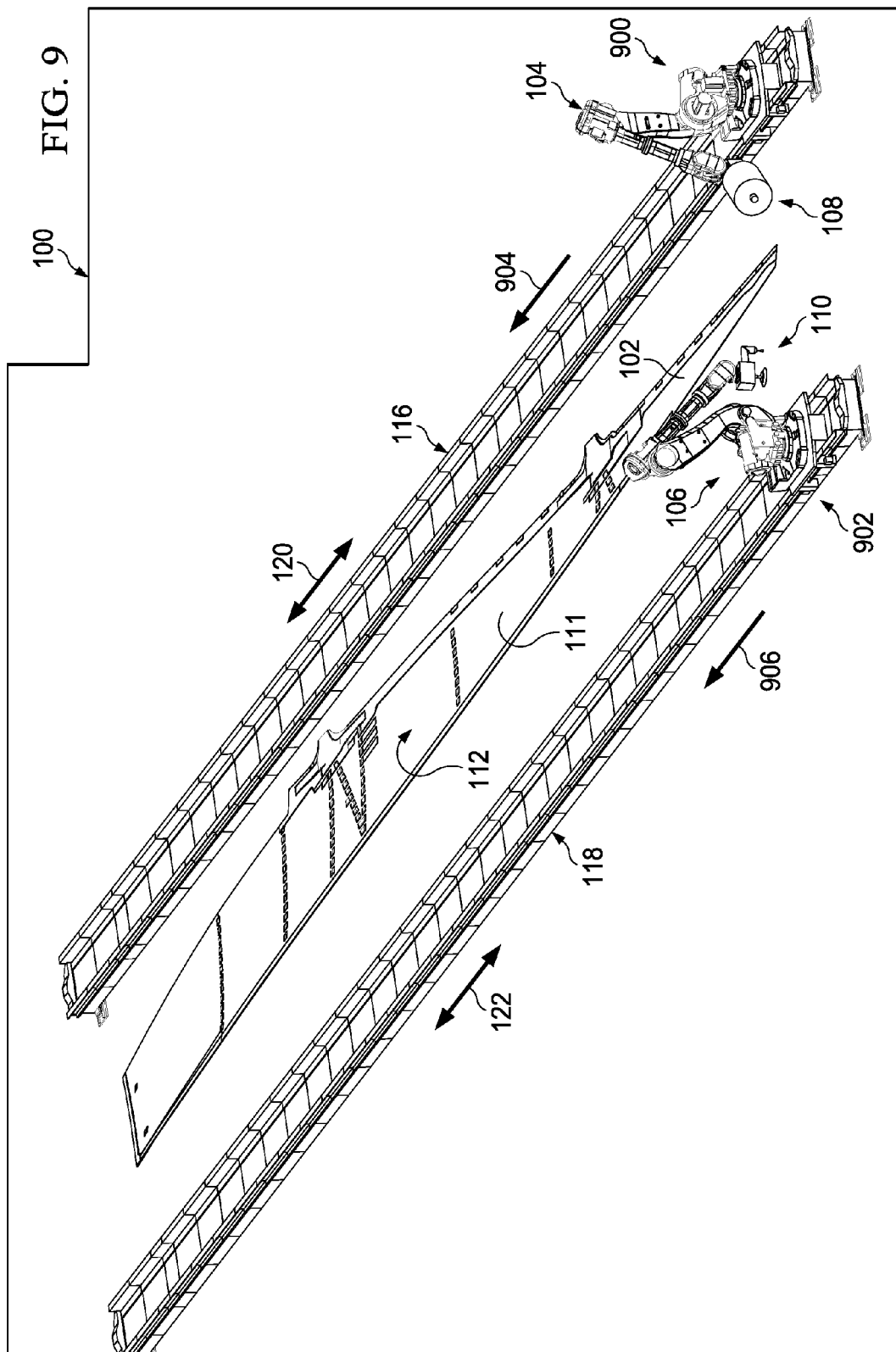


FIG. 10

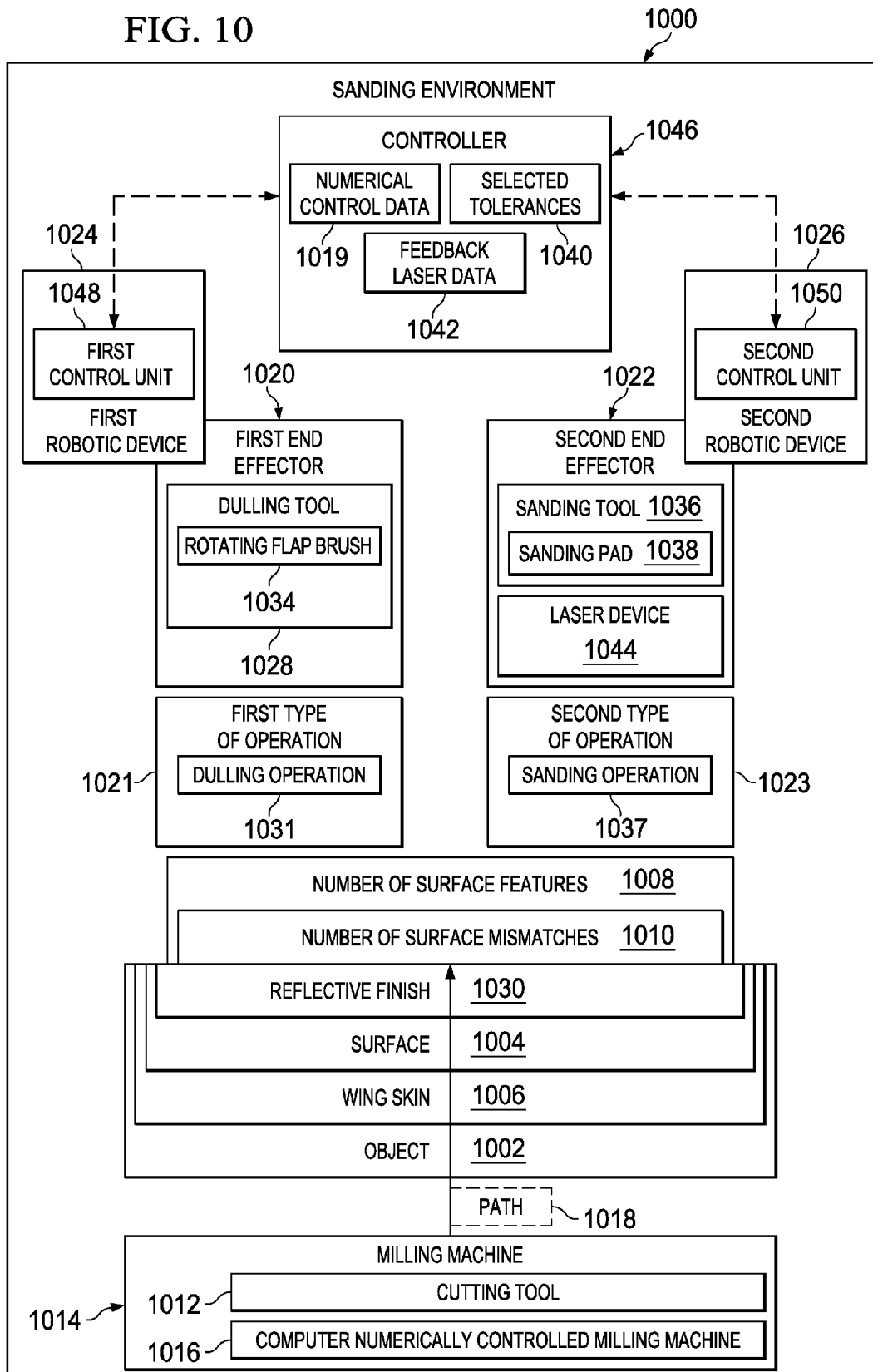


FIG. 11

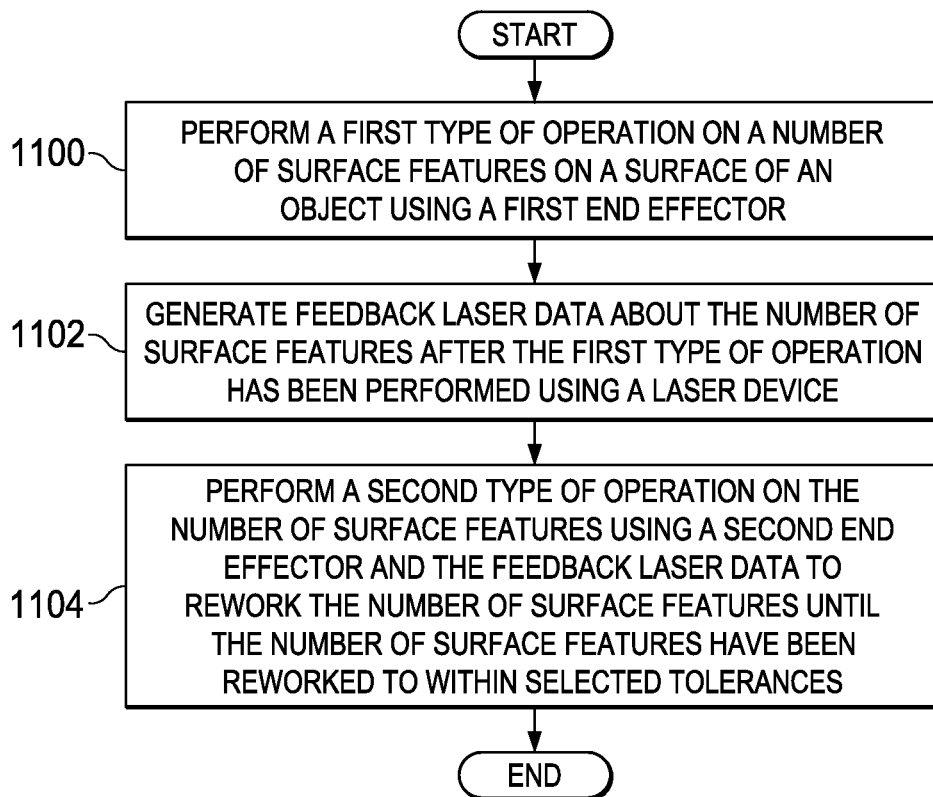


FIG. 12

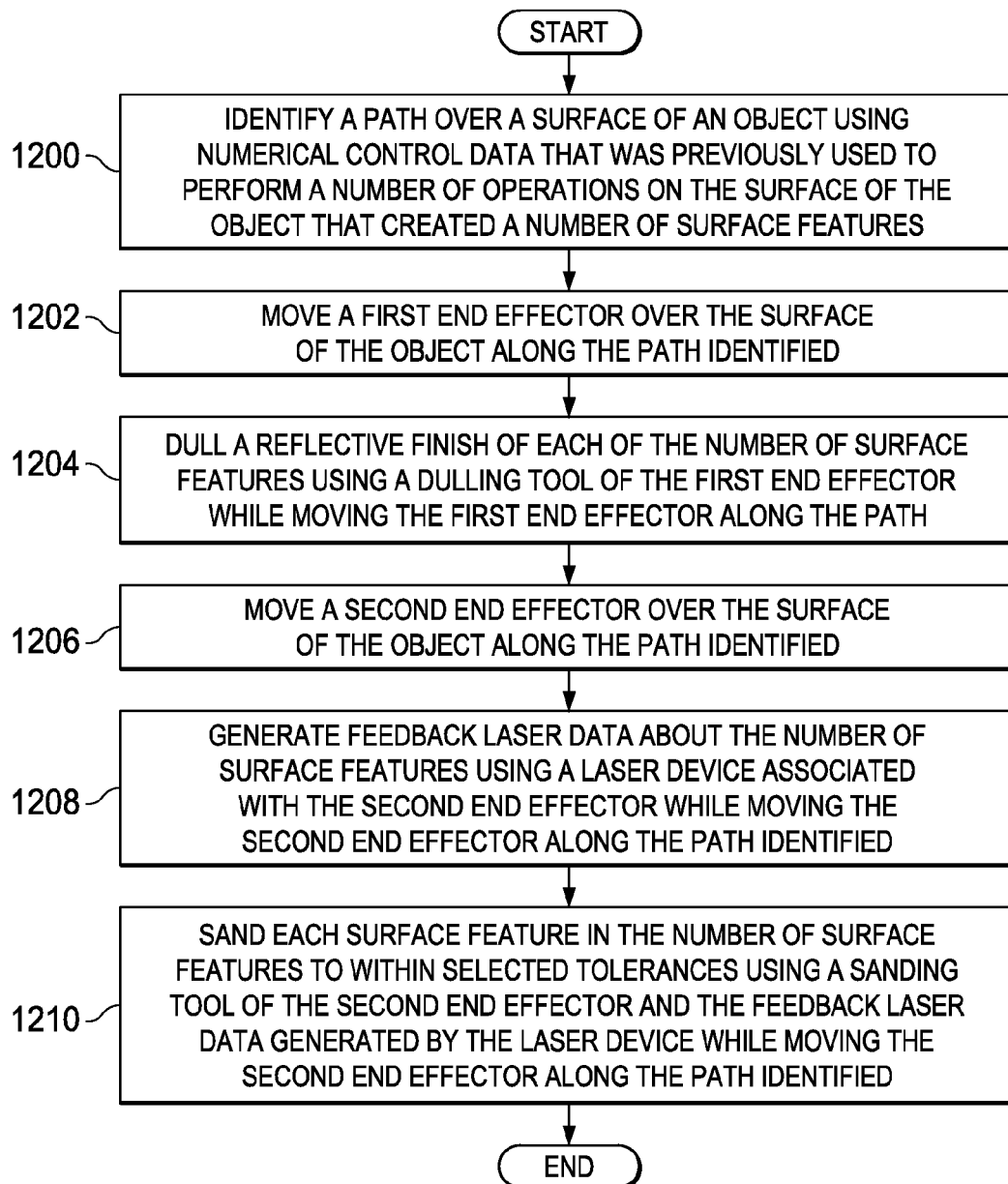
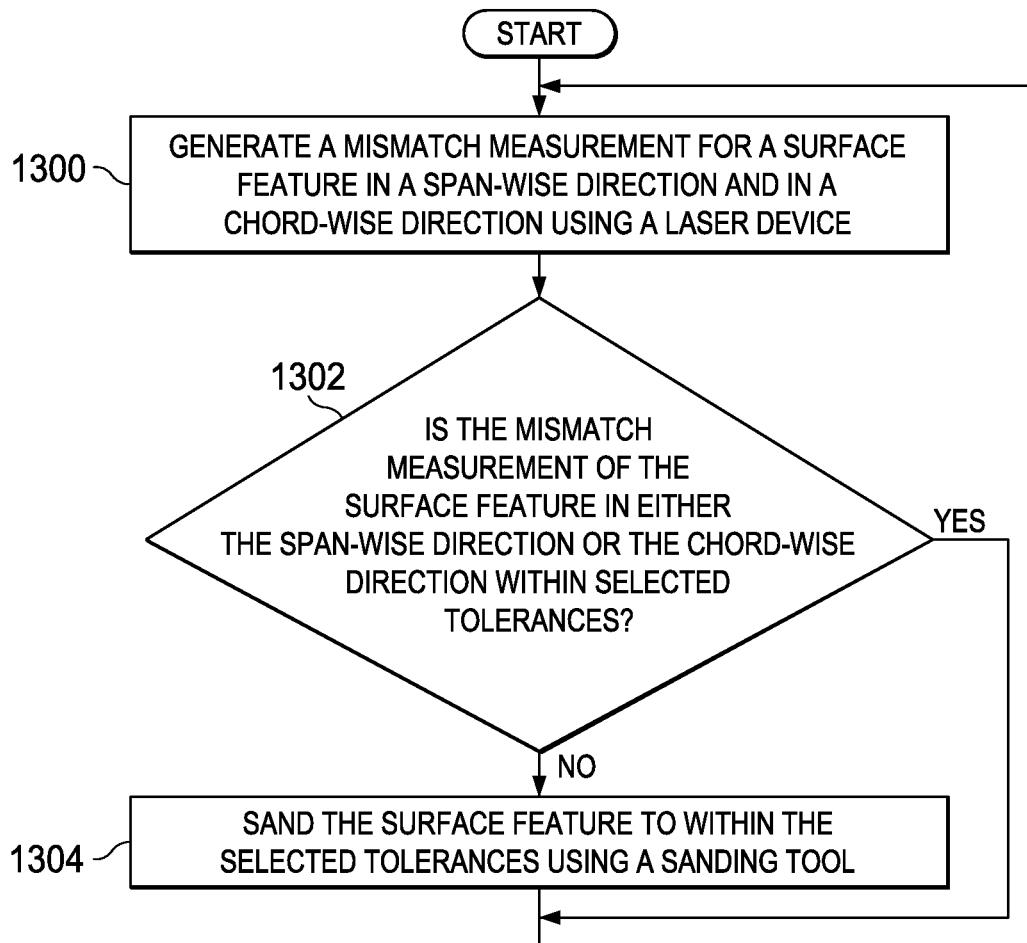
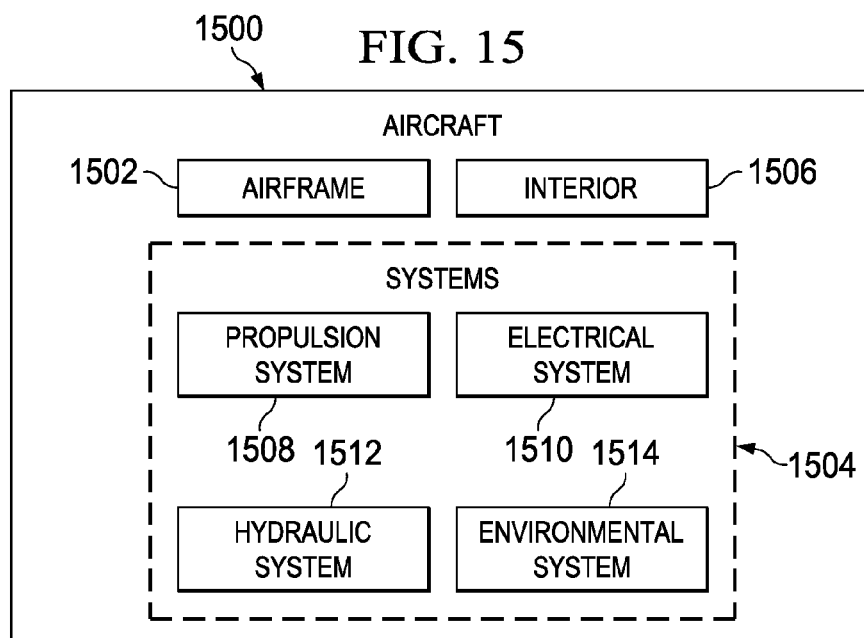
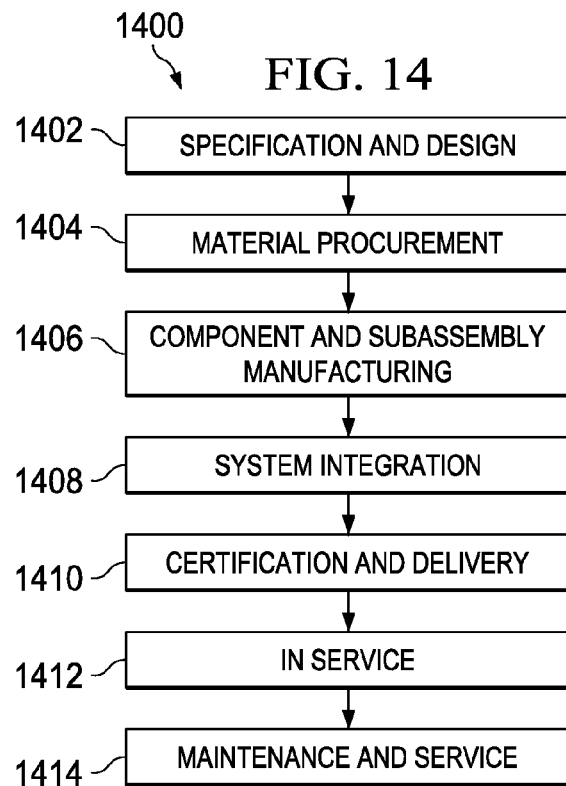


FIG. 13





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AUTOMATED SANDING SYSTEM**BACKGROUND INFORMATION****1. Field**

The present disclosure relates generally to sanding operations and, in particular, to an automated sanding system for performing these sanding operations. Still more particularly, the present disclosure relates to an automated sanding system for sanding surface mismatches on the surfaces of objects.

2. Background

In the manufacturing of certain objects, undesired surface inconsistencies may sometimes be created on the surfaces of these objects. As one illustrative example, milling operations performed during the manufacturing of a wing for an aircraft may result in out-of-tolerance surface inconsistencies. A milling operation is a machining operation that removes material from a workpiece. This operation may be performed by, for example, without limitation, cutting material away from the workpiece, cutting slots into the workpiece, threading, routing, planning, drilling, and/or performing other types of cutting operations.

Milling operations may be performed using a milling machine. A milling machine may include one or more cutting tools. A cutting tool may be used to remove material from an object while the cutting tool is moved relative to the object. In some cases, a surface feature is created on the surface of the object after this operation is performed. This surface inconsistency may be referred to as a "mismatch," a "surface mismatch," or a "cutter mismatch." The mismatch may take the form of, for example, without limitation, a raised edge, a sharp edge, or some other type of surface mismatch. The mismatch may be the result of, for example, a step-over in the direction of travel. As another example, the mismatch may be the result of the cutting tool replacing another cutter tool.

When a mismatch is outside of selected tolerances, the mismatch needs to be reworked to within the selected tolerances. For example, the mismatch may need to be sanded down to within selected tolerances. This sanding operation may also be referred to as "blending" the mismatch with the rest of the surface of the object. The blending of a mismatch with a surface is typically performed using a manually-operated sanding device. However, using a manually-operated sanding device to blend multiple mismatches may be more time-consuming and labor-intensive than desired. Additionally, the quality of the blending of multiple mismatches may be less consistent than desired when performed manually.

Further, depending on the shape, size, and type of object on which these mismatches are located, manually blending these mismatches with the surface of the object may be ergonomically difficult for a human operator. For example, using a manually-operated sanding device may cause ergonomic issues with respect to the hands, wrists, arms, shoulders, and/or back of the human operator operating the sanding device. Therefore, it would be desirable to have a method and apparatus that take into account at least some of the issues discussed above, as well as other possible issues.

SUMMARY

In one illustrative embodiment, a method may be provided. A first type of operation may be performed on a number of surface features on a surface of an object using a first end effector. Feedback laser data may be generated about the number of surface features after the first type of operation has been performed using a laser device. A second type of operation may be performed on the number of surface features

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using a second end effector and the feedback laser data to rework the number of surface features until the number of surface features has been reworked to within selected tolerances.

In yet another illustrative embodiment, an apparatus may comprise a first end effector, a laser device, and a second end effector. The first end effector may be configured to perform a first type of operation on a number of surface features on a surface of an object. The laser device may be configured to generate feedback laser data about the number of surface features after the first type of operation has been performed. The second end effector may be configured to perform a second type of operation on the number of surface features using the feedback laser data to rework the number of surface features until the number of surface features has been reworked to within selected tolerances.

In still another illustrative embodiment, an automated sanding system may comprise a controller, a first end effector, a first robotic device, a second end effector, and a second robotic device. The controller may be configured to identify a path over a surface of an object using numerical control data that was previously used to perform a number of operations on the surface of the object that created a number of surface features. The first end effector may include a dulling tool configured for use in dulling a reflective finish of the number of surface features. The first robotic device may be configured to move the first end effector along the path identified. The first robotic device may be further configured to position the dulling tool over each of the number of surface features. The second end effector may comprise a laser device and a sanding tool. The laser device may be configured to generate feedback laser data about the number of surface features after the reflective finish of the number of surface features has been dulled. The sanding tool may be configured for use in sanding the number of surface features based on the feedback laser data until the number of surface features has been sanded to within selected tolerances. The second robotic device may be configured to move the second end effector along the path identified. The second robotic device may be further configured to position the sanding tool and the laser device over each of the number of surface features.

The features and functions can be achieved independently in various embodiments of the present disclosure or may be combined in yet other embodiments in which further details can be seen with reference to the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The novel features believed characteristic of the illustrative embodiments are set forth in the appended claims. The illustrative embodiments, however, as well as a preferred mode of use, further objectives and features thereof, will best be understood by reference to the following detailed description of an illustrative embodiment of the present disclosure when read in conjunction with the accompanying drawings, wherein:

FIG. 1 is an illustration of an isometric view of a sanding environment in accordance with an illustrative embodiment;

FIG. 2 is an illustration of an enlarged view of a portion of a surface in accordance with an illustrative embodiment;

FIG. 3 is an illustration of an enlarged isometric view of a first robotic device and a first end effector in accordance with an illustrative embodiment;

FIG. 4 is an illustration of an enlarged isometric view of a second robotic device in accordance with an illustrative embodiment;

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FIG. 5 is an illustration of a sanding environment in accordance with an illustrative embodiment;

FIG. 6 is an illustration of an enlarged view of a rotating flap brush positioned over a portion of a surface in accordance with an illustrative embodiment;

FIG. 7 is an illustration of a sanding environment with a first robotic device and a second robotic device moved to new positions in accordance with an illustrative embodiment;

FIG. 8 is an illustration of an enlarged view of a sanding tool positioned over a portion of a surface in accordance with an illustrative embodiment;

FIG. 9 is an illustration of a sanding environment with a first robotic device and a second robotic device moved to final positions in accordance with an illustrative embodiment;

FIG. 10 is an illustration of a sanding environment in the form of a block diagram in accordance with an illustrative embodiment;

FIG. 11 is an illustration of a process for sanding a number of surface features in the form of a flowchart in accordance with an illustrative embodiment;

FIG. 12 is an illustration of a process for sanding a number of surface mismatches on a surface of wing skin in the form of a flowchart in accordance with an illustrative embodiment;

FIG. 13 is an illustration of a process for performing a sanding operation on a surface mismatch in the form of a flowchart in accordance with an illustrative embodiment;

FIG. 14 is an illustration of an aircraft manufacturing and service method in the form of a block diagram in accordance with an illustrative embodiment; and

FIG. 15 is an illustration of an aircraft in the form of a block diagram in which an illustrative embodiment may be implemented.

DETAILED DESCRIPTION

The illustrative embodiments recognize and take into account different considerations. For example, the illustrative embodiments recognize and take into account that it may be desirable to have a method and apparatus for automating the processing of blending surface mismatches. Further, the illustrative embodiments recognize and take into account that it may be desirable to have an automated sanding system capable of working on different types of surfaces, including surfaces that have reflective finishes.

The illustrative embodiments recognize and take into account that some currently available milling machines may be automated. For example, a computer numerical control (CNC) milling machine is a type of automated milling machine. A computer numerical control milling machine may be controlled by a computer using numerical control programming code. The illustrative embodiments recognize and take into account that it may be desirable to use the numerical control programming code used to guide a milling machine along a particular path to program an automated sanding system to follow substantially the same path.

Thus, the illustrative embodiments provide a method and apparatus for automating the sanding of surface mismatches on objects, such as wing skins. Using the automated sanding system described by the illustrative embodiments below may reduce the overall time and labor resources needed for these types of sanding operations.

Referring now to the figures and, in particular, with reference to FIG. 1, an illustration of an isometric view of a sanding environment is depicted in accordance with an illustrative embodiment. As depicted, sanding environment 100 includes wing skin 102, first robotic device 104, and second robotic device 106.

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In this illustrative example, first end effector 108 is associated with first robotic device 104 and second end effector 110 is associated with second robotic device 106. As used herein, when one component is "associated" with another component, the association is a physical association in the depicted examples.

For example, a first component, such as first end effector 108, may be considered to be associated with a second component, such as first robotic device 104, by being secured to the second component, bonded to the second component, mounted to the second component, welded to the second component, fastened to the second component, and/or connected to the second component in some other suitable manner. The first component also may be connected to the second component using a third component. Further, the first component may be considered to be associated with the second component by being formed as part of and/or as an extension of the second component.

As depicted, wing skin 102 may have surface 111. In this illustrative example, surface 111 may have a reflective finish. In other words, surface 111 may be a reflective surface. A milling machine (not shown in this view) is used to perform cutting operations over surface 111 of wing skin 102. The milling machine is a computer numerical control (CNC) milling machine in this illustrative example. Performing the cutting operations using this milling machine creates surface mismatches 112 on surface 111. Surface mismatches 112 may take the form of, for example, raised or sharp edges on surface 111 of wing skin 102.

In this illustrative example, surface mismatches 112 may be out-of-tolerance. In other words, each of surface mismatches 112 may have one or more dimensions outside of selected tolerances. For example, each of surface mismatches 112 may be raised or extend past surface 111 beyond some selected threshold. Surface mismatches 112 may need to be reworked to within selected tolerances. In particular, surface mismatches 112 may need to be sanded down and smoothed. More particularly, surface mismatches 112 may need to be blended with surface 111 to within selected tolerances.

First end effector 108 may be used to dull the reflective finish on and around each of surface mismatches 112. Dulling this reflective finish may allow a laser device (not shown in this view) associated with second end effector 110 to better measure surface mismatches 112. Second end effector 110 may be used to sand each of surface mismatches 112 to within selected tolerances based on feedback laser data from this laser device.

As depicted, surface mismatches 112 may be present on different portions of surface 111. For example, a portion of surface mismatches 112 may be present on portion 114 of surface 111 of wing skin 102.

In this illustrative example, first robotic device 104 may be attached to rail system 116, while second robotic device 106 may be attached to rail system 118. Wing skin 102 has been positioned between these rail systems. First robotic device 104 may move in either direction along axis 120 on rail system 116 to move first end effector 108 relative to wing skin 102. Similarly, second end effector 110 may move in either direction along axis 122 on rail system 118 to move second end effector 110 relative to wing skin 102.

As depicted, first robotic device 104 and second robotic device 106 are in initial position 124 and initial position 126, respectively. These initial positions may be the positions at which first robotic device 104 and second robotic device 106 begin when a wing, such as wing skin 102, is moved into a selected position between rail system 116 and rail system 118. The process by which first robotic device 104 with first

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end effector **108** and second robotic device **106** with second end effector **110** are used to sand surface mismatches **112** on surface **111** of wing skin **102** to within selected tolerances is described in the figures below.

With reference now to FIG. 2, an illustration of an enlarged view of portion **114** of surface **111** from FIG. 1 is depicted in accordance with an illustrative embodiment. As depicted, set of surface mismatches **200** are present on portion **114** of surface **111**. Set of surface mismatches **200** may be a portion of surface mismatches **112** depicted in FIG. 1.

In this illustrative example, set of surface mismatches **200** may be aligned along path **202**. Path **202** may be the path used by the milling machine to perform cutting operations on portion **114** of surface **111**. Surface mismatch **204** is an example of one of set of surface mismatches **200**. As depicted, surface mismatch **204** comprises a portion of surface **111** being raised above the surrounding portion of surface **111**. Surface mismatch **204** may be sanded such that the portion of surface **111** included in surface mismatch **204** may be blended with the portion of surface **111** surrounding surface mismatch **204**.

With reference now to FIG. 3, an illustration of an enlarged isometric view of first robotic device **104** and first end effector **108** from FIG. 1 is depicted in accordance with an illustrative embodiment. As depicted, first end effector **108** includes attachment structure **300** and dulling tool **302**. Attachment structure **300** is used to attach first end effector **108** to first robotic device **104**.

Dulling tool **302** takes the form of rotating flap brush **304** in this illustrative example. In particular, rotating flap brush **304** may be rotated about axis **306**. Rotating flap brush **304** has outer surface **308**. Outer surface **308** may have a texture configured to remove a finish, such as the reflective finish on surface **111** of wing skin **102** in FIGS. 1-2. In this illustrative example, outer surface **308** may be an abrasive surface.

As depicted, first robotic device **104** takes the form of robotic arm **310** connected to base **312**. Robotic arm **310** may be configured to move first end effector **108**, and thereby rotating flap brush **304**, in a number of different directions. Base **312** is configured for attachment to rail system **116** from FIG. 1.

With reference now to FIG. 4, an illustration of an enlarged isometric view of second robotic device **106** from FIG. 1 is depicted in accordance with an illustrative embodiment. As depicted, second end effector **110** includes attachment structure **400**, sanding tool **402**, laser device **404**, and control box **405**. Attachment structure **400** is used to attach second end effector **110** to second robotic device **106**.

Sanding tool **402** takes the form of sanding pad **406** in this illustrative example. Sanding pad **406** may have sanding surface **408** that may be used for sanding when sanding pad **406** is rotated about axis **410**. Control box **405** may include a control unit (not shown) that is used to control the operation of sanding pad **406**. The control unit may be, for example, a processor unit that controls a number of parameters that may include, but are not limited to, the rotational speed of sanding pad **406** about axis **410**, the number of turns completed for each surface mismatch being sanded, the pressure applied to a surface by sanding pad **406**, and other types of parameters.

The pressure applied to a surface by sanding pad **406** may be controlled by controlling the movement of sanding pad **406** in a direction along axis **410**. For example, sanding pad **406** may be moved down towards a surface to apply pressure to the surface.

In this illustrative example, laser device **404** is attached to control box **405**. In this manner, laser device **404** is associated with second end effector **110** by being part of second end

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effector **110**. Laser device **404** may be used to generate laser beam **412** that is used to measure a surface mismatch. These laser measurements may be sent to the control unit and used by the control unit to generate one or more commands for second robotic device **106** and/or to adjust the operation of sanding pad **406**.

As depicted, second robotic device **106** takes the form of robotic arm **414** connected to base **416**. Robotic arm **414** may be configured to move second end effector **110**, and thereby sanding pad **406**, in a number of different directions. Base **416** is configured for attachment to rail system **118** from FIG. 1.

With reference now to FIG. 5, an illustration of sanding environment **100** from FIG. 1 is depicted in accordance with an illustrative embodiment. In this illustrative example, first robotic device **104** has been moved in the direction of arrow **500** from initial position **124** in FIG. 1 to position **502**. In position **502**, first robotic device **104** may position rotating flap brush **304** over portion **114** of surface **111** such that the reflective finish on set of surface mismatches **200** may be dulled.

Turning now to FIG. 6, an illustration of an enlarged view of rotating flap brush **304** positioned over portion **114** of surface **111** is depicted in accordance with an illustrative embodiment. In particular, the enlarged view of rotating flap brush **304** positioned over portion **114** of surface **111** is depicted taken with respect to lines 6-6 in FIG. 5.

First robotic device **104** is configured to guide rotating flap brush **304** along path **202** based on the numerical control programming code that was used to control the milling machine that performed cutting operations along path **202**. In this illustrative example, first robotic device **104** is configured to rotate rotating flap brush **304** in the direction of arrow **600** about axis **306**, while moving rotating flap brush **304** in the direction of arrow **602** substantially along path **202**. As rotating flap brush **304** is moved in the direction of arrow **602**, rotating flap brush **304** contacts surface **111** and consequently, dulls the reflective finish on portion **114** of surface **111**.

In particular, the reflective finish on set of surface mismatches **200** and the portion of surface **111** surrounding set of surface mismatches **200** is dulled. By dulling this reflective finish, rotating flap brush **304** prepares this area for laser device **404** in FIG. 4. Laser device **404** may be unable to take measurements of surface **111** with a desired level of accuracy when surface **111** is reflective.

With reference now to FIG. 7, an illustration of sanding environment **100** from FIG. 1 with first robotic device **104** and second robotic device **106** moved to new positions is depicted in accordance with an illustrative embodiment. In this illustrative example, first robotic device **104** has completed dulling operations on portion **114** of surface **111** and has moved to position **700**. Further, second robotic device **106** has been moved in the direction of arrow **701** to position **702**. In position **702**, second robotic device **106** may position sanding pad **406** over portion **114** of surface **111** and set of surface mismatches **200** on portion **114** of surface **111**.

Turning now to FIG. 8, an illustration of an enlarged view of sanding tool **402** positioned over portion **114** of surface **111** is depicted in accordance with an illustrative embodiment. In particular, the enlarged view of sanding tool **402** positioned over portion **114** of surface **111** is depicted taken with respect to lines 8-8 in FIG. 7.

Second robotic device **106** is configured to guide sanding pad **406** along path **202** based on the numerical control programming code that was used to control the milling machine that performed cutting operations along path **202**. Second robotic device **106** rotates sanding pad **406** in the direction of

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arrow **800** about axis **410**, while moving sanding pad **406** in the direction of arrow **802** substantially along path **202** to each of set of surface mismatches **200**.

The control unit in control box **405** uses feedback laser data generated by laser device **404** to control the operation, movement, and positioning of sanding pad **406** over each of set of surface mismatches **200** such that each of set of surface mismatches **200** is sanded to within selected tolerances.

With reference now to FIG. **9**, an illustration of sanding environment **100** from FIG. **1** with first robotic device **104** and second robotic device **106** moved to final positions is depicted in accordance with an illustrative embodiment. In this illustrative example, all sanding operations have been completed and all of surface mismatches **112** have been sanded down and blended with the rest of surface **111** to within selected tolerances. First robotic device **104** and second robotic device **106** have moved to final position **900** and final position **902**, respectively.

Once wing skin **102** has been moved out of sanding environment **100**, first robotic device **104** and second robotic device **106** may be moved back to initial position **124** and initial position **126**, respectively, from FIG. **1**, to perform sanding operations on a different wing. In this manner, the process of sanding surface mismatches on wing surfaces may be automated.

The illustrations of sanding environment **100**, wing skin **102**, first robotic device **104**, second robotic device **106**, first end effector **108**, and second end effector **110** in FIGS. **1-9** are not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be optional.

The different components shown in FIGS. **1-9** may be illustrative examples of how components shown in block form in FIG. **10** below can be implemented as physical structures. Additionally, some of the components in FIGS. **1-9** may be combined with components in FIG. **10**, used with components in FIG. **10**, or a combination of the two.

With reference now to FIG. **10**, an illustration of a sanding environment is depicted in the form of a block diagram in accordance with an illustrative embodiment. Sanding environment **100** in FIG. **1** is an example of one manner in which sanding environment **1000** may be implemented. As depicted, sanding environment **1000** may be an environment in which sanding operations may be performed on surface **1004** of object **1002**. In this illustrative example, object **1002** takes the form of wing skin **1006**. However, in other illustrative examples, object **1002** may take the form of some other type of object such as, but not limited to, a fuselage skin, a metal door, a metal plate, a spar, or some other type of object.

Number of surface features **1008** may be present on surface **1004**. As used herein, a "number of" items may include one or more items. In this manner, number of surface features **1008** may include one or more surface features.

Number of surface features **1008** may take the form of number of surface mismatches **1010** in this illustrative example. Number of surface mismatches **1010** may have been created by cutting tool **1012**. In one illustrative example, cutting tool **1012** may be part of milling machine **1014**. In particular, milling machine **1014** may take the form of computer numerically controlled milling machine **1016**. Cutting tool **1012** may have been controlled by milling machine **1014** to perform cutting operations along path **1018** on surface **1004** based on numerical control data **1019**. Numerical control data **1019** may comprise numerical control programming code.

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First end effector **1020** and second end effector **1022** may be used to rework number of surface mismatches **1010** to within selected tolerances. In particular, first end effector **1020** may be used to perform first type of operation **1021** on number of surface mismatches **1010**, while second end effector **1022** may be used to perform second type of operation **1023** on number of surface mismatches **1010**.

As depicted, first end effector **1020** is associated with first robotic device **1024** and second end effector **1022** is associated with second robotic device **1026** in this illustrative example. First robotic device **1024** and second robotic device **1026** may take the form of, for example, robotic arms.

First end effector **1020** may include dulling tool **1028**. Dulling tool **1028** is configured to perform dulling operation **1031**, which includes dulling reflective finish **1030** on the portion of surface **1004** along path **1018**. Dulling operation **1031** may be an example of first type of operation **1021**. In this manner, reflective finish **1030** on number of surface mismatches **1010** and the portion of surface **1004** surrounding number of surface mismatches **1010** along path **1018** may be dulled. In one illustrative example, dulling tool **1028** takes the form of rotating flap brush **1034**.

First robotic device **1024** may control the movement of first end effector **1020**. For example, first robotic device **1024** may be used to move and position dulling tool **1028** of first end effector **1020** relative to surface **1004**. First robotic device **1024** may identify path **1018** along which number of surface mismatches **1010** was formed based on numerical control data **1019**. First robotic device **1024** may move dulling tool **1028** along path **1018** such that reflective finish **1030** of the portion of surface **1004** along path **1018** may be dulled by dulling tool **1028**.

Second end effector **1022** may include sanding tool **1036**. Sanding tool **1036** is configured to perform sanding operation **1037**, which includes sanding number of surface mismatches **1010**. Sanding operation **1037** is an example of second type of operation **1023**. In one illustrative example, sanding tool **1036** takes the form of sanding pad **1038**.

Second robotic device **1026** may control the movement of second end effector **1022**. For example, second robotic device **1026** may be used to move and position sanding tool **1036** of second end effector **1022** relative to surface **1004**. Second robotic device **1026** may identify path **1018** along which number of surface mismatches **1010** was formed based on numerical control data **1019**. Second robotic device **1026** may move sanding tool **1036** to each of number of surface mismatches **1010** such that each of number of surface mismatches **1010** may be sanded down to within selected tolerances **1040**.

In this illustrative example, sanding tool **1036** performs sanding operation **1037** based on feedback laser data **1042** received from laser device **1044**. Laser device **1044** may be associated with second end effector **1022**. In this illustrative example, laser device **1044** is considered part of second end effector **1022**. However, in other illustrative examples, laser device **1044** may be considered separate from second end effector **1022**.

Laser device **1044** is configured to generate feedback laser data **1042** by measuring each of number of surface mismatches **1010** as second end effector **1022** is moved along path **1018**. In this illustrative example, controller **1046** may receive feedback laser data **1042** and control operation of sanding tool **1036** based on feedback laser data **1042**. For example, controller **1046** may use feedback laser data **1042** to adjust a number of parameters for sanding tool **1036**. These parameters may include, for example, without limitation,

rotational speed, number of turns, pressure applied to a surface, and/or other types of parameters.

In one illustrative example, controller **1046** is formed by first control unit **1048** and second control unit **1050**. First control unit **1048** may be implemented within first robotic device **1024** and used to control operation of first robotic device **1024** and first end effector **1020**.

Second control unit **1050** may be implemented within one of second robotic device **1026** and second end effector **1022**. In some cases, a portion of second control unit **1050** may be implemented in second robotic device **1026**, while another portion of second control unit **1050** may be implemented within second end effector **1022**.

In this illustrative example, first robotic device **1024** and second robotic device **1026** may be programmed using numerical control data **1019** such that first end effector **1020** and second end effector **1022**, respectively, may be moved down a centerline of path **1018**. However, in other illustrative examples, numerical control data **1019** may be used to identify a modified path. This modified path may be offset from a centerline of path **1018** by some distance. This distance may be constant along path **1018** or may vary along path **1018**, depending on the implementation. The modified path may then be used to guide first end effector **1020** and second end effector **1022** along surface **1004** of object **1002** instead of path **1018**. The modified path may more accurately indicate the location of each of number of surface mismatches **1010**.

The illustration of sanding environment **1000** in FIG. **10** is not meant to imply physical or architectural limitations to the manner in which an illustrative embodiment may be implemented. Other components in addition to or in place of the ones illustrated may be used. Some components may be optional. Also, the blocks are presented to illustrate some functional components. One or more of these blocks may be combined, divided, or combined and divided into different blocks when implemented in an illustrative embodiment.

In some illustrative examples, number of surface features **1008** may include a number of edges of object **1002**. These edges may be the outer edges of object **1002**. In these examples, first end effector **1020** and/or second end effector **1022** may be used to change the shape of these edges. As one illustrative example, rotating flap brush **1034** may be used to smooth out the outer edges of object **1002**. In this manner, rotating flap brush **1034** may be used to perform other operations in addition to dulling operation **1031**.

The outer edges of object **1002** may be radiused to prepare surface **1004** of object **1002** for, for example, a shot peening process. A shot peening process involves impacting a surface with shot particles with sufficient force to cause plastic deformation of surface **1004** of object **1002**. However, when the shot particles impact a sharp edge, such as the outer edge of an object, the force of the shot particles may cause an undesired inconsistency to form at the edge of the object.

Consequently, it may be desirable to use rotating flap brush **1034** to smooth out the edges of object **1002** prior to performing the shot peening process. This type of smoothing of the edges may be referred to as "edge breaking" or "edge radius-ing." Numerical control data **1019** may be used to program first robotic device **1024** to move rotating flap brush **1034** along the edges of object **1002** to smooth out or round out these edges. In this manner, an edge of object **1002** may be radiused using first end effector **1020** based on numerical control data **1019** used to form object **1002**.

With reference now to FIG. **11**, an illustration of a process for sanding a number of surface features is depicted in the form of a flowchart in accordance with an illustrative embodi-

ment. The process illustrated in FIG. **11** may be implemented in sanding environment **100** in FIG. **1**.

The process may begin by performing a first type of operation on a number of surface features on a surface of an object using a first end effector (operation **1100**). Feedback laser data may then be generated about the number of surface features after the first type of operation has been performed using a laser device (operation **1102**).

A second type of operation may be performed on the number of surface features using a second end effector and the feedback laser data to rework the number of surface features until the number of surface features has been reworked to within selected tolerances (operation **1104**), with the process terminating thereafter.

With reference now to FIG. **12**, an illustration of a process for sanding a number of surface mismatches on a surface of wing skin is depicted in the form of a flowchart in accordance with an illustrative embodiment. The process illustrated in FIG. **12** may be implemented in sanding environment **100** in FIG. **1**.

The process may begin by identifying a path over a surface of an object using numerical control data that was previously used to perform a number of operations on the surface of the object that created a number of surface features (operation **1200**). A first end effector may be moved over the surface of the object along the path identified (operation **1202**). A reflective finish of each of the number of surface features may be dulled using a dulling tool of the first end effector while moving the first end effector along the path (operation **1204**).

A second end effector may be moved over the surface of the object along the path identified (operation **1206**). Feedback laser data may be generated about the number of surface features using a laser device associated with the second end effector while moving the second end effector along the path identified (operation **1208**). Each surface feature in the number of surface features may be sanded to within selected tolerances using a sanding tool of the second end effector and the feedback laser data generated by the laser device while moving the second end effector along the path identified (operation **1210**), with the process then terminating thereafter.

With reference now to FIG. **13**, an illustration of a process for performing a sanding operation on a surface mismatch is depicted in the form of a flowchart in accordance with an illustrative embodiment. The process illustrated in FIG. **13** may be implemented in sanding environment **100** in FIG. **1**. This process may be used to implement operations **1208** and **1210** in FIG. **12**.

The process begins by generating a mismatch measurement for a surface feature in a span-wise direction and in a chord-wise direction using a laser device (operation **1300**). A determination may be made as to whether the mismatch measurement of the surface feature in either the span-wise direction or the chord-wise direction is within selected tolerances (operation **1302**).

If the mismatch measurement of the surface feature is within selected tolerances in both the span-wise direction and the chord-wise direction, the process terminates. Otherwise, if the mismatch measurement of the surface feature in either the span-wise direction or the chord-wise direction is not within the selected tolerances, a sanding tool is used to sand the surface feature to within the selected tolerances (operation **1304**), with the process then returning to operation **1300** as described above. In this manner, the surface feature that has been sanded may be reevaluated by generating another mismatch measurement for the surface feature.

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Illustrative embodiments of the disclosure may be described in the context of aircraft manufacturing and service method **1400** as shown in FIG. **14** and aircraft **1500** as shown in FIG. **15**. Turning first to FIG. **14**, an illustration of an aircraft manufacturing and service method is depicted in the form of a block diagram in accordance with an illustrative embodiment. During pre-production, aircraft manufacturing and service method **1400** may include specification and design **1402** of aircraft **1500** in FIG. **15** and material procurement **1404**.

During production, component and subassembly manufacturing **1406** and system integration **1408** of aircraft **1500** in FIG. **15** takes place. Thereafter, aircraft **1500** in FIG. **15** may go through certification and delivery **1410** in order to be placed in service **1412**. While in service **1412** by a customer, aircraft **1500** in FIG. **15** is scheduled for routine maintenance and service **1414**, which may include modification, reconfiguration, refurbishment, and other maintenance or service.

Each of the processes of aircraft manufacturing and service method **1400** may be performed or carried out by a system integrator, a third party, and/or an operator. In these examples, the operator may be a customer. For the purposes of this description, a system integrator may include, without limitation, any number of aircraft manufacturers and major-system subcontractors; a third party may include, without limitation, any number of vendors, subcontractors, and suppliers; and an operator may be an airline, a leasing company, a military entity, a service organization, and so on.

With reference now to FIG. **15**, an illustration of an aircraft is depicted in the form of a block diagram in which an illustrative embodiment may be implemented. In this example, aircraft **1500** is produced by aircraft manufacturing and service method **1400** in FIG. **14** and may include airframe **1502** with plurality of systems **1504** and interior **1506**. Examples of systems **1504** include one or more of propulsion system **1508**, electrical system **1510**, hydraulic system **1512**, and environmental system **1514**. Any number of other systems may be included. Although an aerospace example is shown, different illustrative embodiments may be applied to other industries, such as the automotive industry.

Apparatuses and methods embodied herein may be employed during at least one of the stages of aircraft manufacturing and service method **1400** in FIG. **14**. In one illustrative example, components or subassemblies produced in component and subassembly manufacturing **1406** in FIG. **14** may be fabricated or manufactured in a manner similar to components or subassemblies produced while aircraft **1500** is in service **1412** in FIG. **14**. As yet another example, one or more apparatus embodiments, method embodiments, or a combination thereof may be utilized during production stages, such as component and subassembly manufacturing **1406** and system integration **1408** in FIG. **14**. One or more apparatus embodiments, method embodiments, or a combination thereof may be utilized while aircraft **1500** is in service **1412** and/or during maintenance and service **1414** in FIG. **14**. The use of a number of the different illustrative embodiments may substantially expedite the assembly of and/or reduce the cost of aircraft **1500**.

The flowcharts and block diagrams in the different depicted embodiments illustrate the architecture, functionality, and operation of some possible implementations of apparatuses and methods in an illustrative embodiment. In this regard, each block in the flowcharts or block diagrams may represent a module, a segment, a function, and/or a portion of an operation or step.

In some alternative implementations of an illustrative embodiment, the function or functions noted in the blocks

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may occur out of the order noted in the figures. For example, in some cases, two blocks shown in succession may be executed substantially concurrently, or the blocks may sometimes be performed in the reverse order, depending upon the functionality involved. Also, other blocks may be added in addition to the illustrated blocks in a flowchart or block diagram.

The description of the different illustrative embodiments has been presented for purposes of illustration and description, and is not intended to be exhaustive or limited to the embodiments in the form disclosed. Many modifications and variations will be apparent to those of ordinary skill in the art. Further, different illustrative embodiments may provide different features as compared to other desirable embodiments. The embodiment or embodiments selected are chosen and described in order to best explain the principles of the embodiments, the practical application, and to enable others of ordinary skill in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular use contemplated.

What is claimed is:

1. A method comprising:

identifying a path over a surface of an object using numerical control data that was used to create a number of surface features created by a number of operations performed on the surface of the object;

performing a first type of operation on the number of surface features on the surface of the object using a first end effector by guiding the first end effector along the path; generating feedback laser data about the number of surface features after the first type of operation has been performed using a laser device; and

performing a second type of operation on the number of surface features using a second end effector and the feedback laser data, by guiding the second end effector along the path to rework the number of surface features until the number of surface features has been reworked to within selected tolerances;

wherein performing the first type of operation comprises dulling a reflective finish of a surface feature in the number of surface features using a dulling tool to allow the laser device to measure the surface feature and generate the feedback laser data.

2. The method of claim 1, wherein performing the second type of operation comprises:

sanding the surface feature using a sanding tool and the feedback laser data until the surface feature has been sanded to within the selected tolerances.

3. The method of claim 1, wherein performing the first type of operation comprises:

moving the first end effector over the surface of the object along the path identified; and

dulling the reflective finish of each of the number of surface features using the dulling tool of the first end effector while moving the first end effector along the path.

4. The method of claim 1, wherein performing the second type of operation comprises:

moving the second end effector over the surface of the object along the path identified; and

sanding each surface feature in the number of surface features to within the selected tolerances using a sanding tool of the second end effector and the feedback laser data while moving the second end effector along the path.

5. The method of claim 1, wherein generating the feedback laser data comprises:

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generating a mismatch measurement for a surface feature in the number of surface features in a span-wise direction and in a chord-wise direction using the laser device, wherein the surface feature is a surface mismatch.

6. The method of claim 5, wherein performing the second type of operation comprises:

determining whether the mismatch measurement for the surface feature in either the span-wise direction or the chord-wise direction is within selected tolerances; and sanding the surface feature using a sanding tool of the second end effector in response to a determination that the mismatch measurement for the surface feature in either the span-wise direction or the chord-wise direction is not within the selected tolerances.

7. The method of claim 1 further comprising:

radiusing an edge of the object using the first end effector based on numerical control data used to form the object.

8. An apparatus comprising:

a controller configured to identify a path over a surface of an object using numerical control data that was used to create a number of surface features created by a number of operations performed on the surface of the object;

a first end effector configured to perform a first type of operation on the number of surface features on the surface of the object by guiding the first end effector along the path;

a laser device configured to generate feedback laser data about the number of surface features after the first type of operation has been performed; and

a second end effector configured to perform a second type of operation on the number of surface features using the feedback laser data by guiding the second end effector along the path to rework the number of surface features until the number of surface features has been reworked to within selected tolerances;

wherein the first end effector comprises a dulling tool configured to dull a reflective finish of a surface feature in the number of surface features to allow the laser device to measure the surface feature and generate the feedback laser data.

9. The apparatus of claim 8, wherein the dulling tool is a rotating flap brush.

10. The apparatus of claim 8, wherein the second end effector comprises:

a sanding tool configured to sand the surface feature using the feedback laser data until the surface feature has been sanded to within the selected tolerances.

11. The apparatus of claim 10, wherein the sanding tool is a sanding pad.

12. The apparatus of claim 8, wherein the controller is configured to control a first robotic device to move the first end effector over the surface of the object along the path identified.

13. The apparatus of claim 8, wherein the controller is configured to control a second robotic device to move the second end effector over the surface of the object along the path identified.

14. The apparatus of claim 8, wherein the second end effector comprises:

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a control unit configured to receive the feedback laser data about a surface feature in the number of surface features from the laser device and identify a number of parameters for sanding the surface feature based on the feedback laser data; and

a sanding tool configured to sand the surface feature based on the number of parameters.

15. The apparatus of claim 8, wherein a surface feature in the number of surface features is a surface mismatch.

16. An automated sanding system comprising:

a controller configured to identify a path over a surface of an object using numerical control data that was previously used to create a number of surface features by a number of operations performed on the surface of the object;

a first end effector that includes a dulling tool configured for use in dulling a reflective finish of the number of surface features;

a first robotic device configured to move the first end effector along the path identified and position the dulling tool over each of the number of surface features;

a second end effector comprising:

a laser device configured to generate feedback laser data about the number of surface features after the reflective finish of the number of surface features has been dulled; and

a sanding tool configured for use in sanding the number of surface features based on the feedback laser data until the number of surface features has been sanded to within selected tolerances; and

a second robotic device configured to move the second end effector along the path identified and position the sanding tool and the laser device over the each of the number of surface features.

17. The method of claim 1, wherein the first type of operation is performed before the second type of operation, and wherein the first type of operation is different from the second type of operation.

18. The automated sanding system of claim 16, wherein generating the feedback laser data comprises:

generating a mismatch measurement for a surface feature in the number of surface features in a span-wise direction and in a chord-wise direction using the laser device, wherein the surface feature is a surface mismatch.

19. The automated sanding system of claim 18, further comprising:

determining whether the mismatch measurement for the surface feature in either the span-wise direction or the chord-wise direction is within selected tolerances; and sanding the surface feature using the sanding tool of the second end effector in response to a determination that the mismatch measurement for the surface feature in either the span-wise direction or the chord-wise direction is not within the selected tolerances.

20. The automated sanding system of claim 16 further comprising:

radiusing an edge of the object using the first end effector based on numerical control data used to form the object.

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